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TILT ANALYSIS OF PHOTOGRAPHY TAKEN WITH CAMERA 9 (B CONFIGURATION)

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The purpose of this report is to present a simple method of obtaining the tilt of photography taken with camera 9 (B configuration) in mode one. Although a thorough evaluation of this method of tilt determination has not been made, this report is being published to provide a basis for further study.

The method is based on the principle that if the aircraft does not deviate from its course, the dihedral angle between (1) a plane that passes through two consecutive exposure stations (nodes) and through any point in object space that is imaged in the overlap area and (2) the plane of the horizon will not vary between consecutive exposures (see Figure 1).

Deviations in the direction of flight will cause station eccentricity, introducing an angular error of approximately 3 minutes of arc per 100 feet of deviated distance (see Figure 2). Information concerning the flying characteristics of the aircraft indicates that it is not possible for the aircraft to deviate 100 feet between exposures. The maximum value is nearer 30 feet between two consecutive exposures, or during a time of 4.8 seconds.

Swing was assumed nominal throughout the test for the following reason: Forty-nine different swing determinations were made from the high obliques from operational photography and from obliques taken over the Arizona control range. The results of the determinations, which give an indication of the aircraft's fore and aft (pitch) stability, are as follows.

a. 20 values were 0°30' or less from nominal
b. 15 values were 1°00' or less from nominal
c. 13 values were 1°30' or less from nominal
d. 1 value was 1°34' from nominal

Because eccentricity of station is small in relation to the distance from camera to object and because swing can be assumed nominal, it is possible to determine the tilt of all exposures within practical limits. The

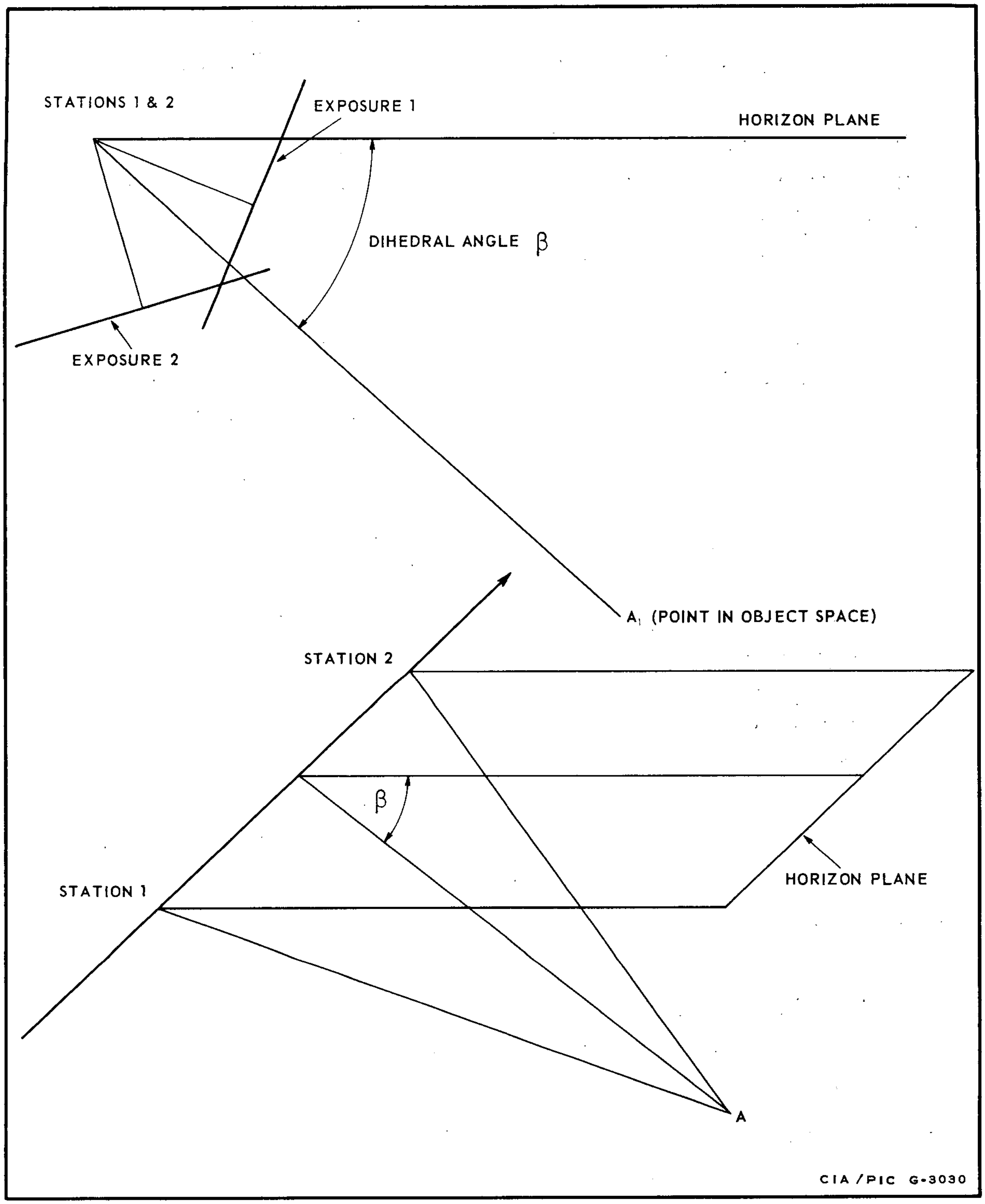

FIGURE 1. DIHEDRAL ANGLE BETWEEN CONSECUTIVE EXPOSURES

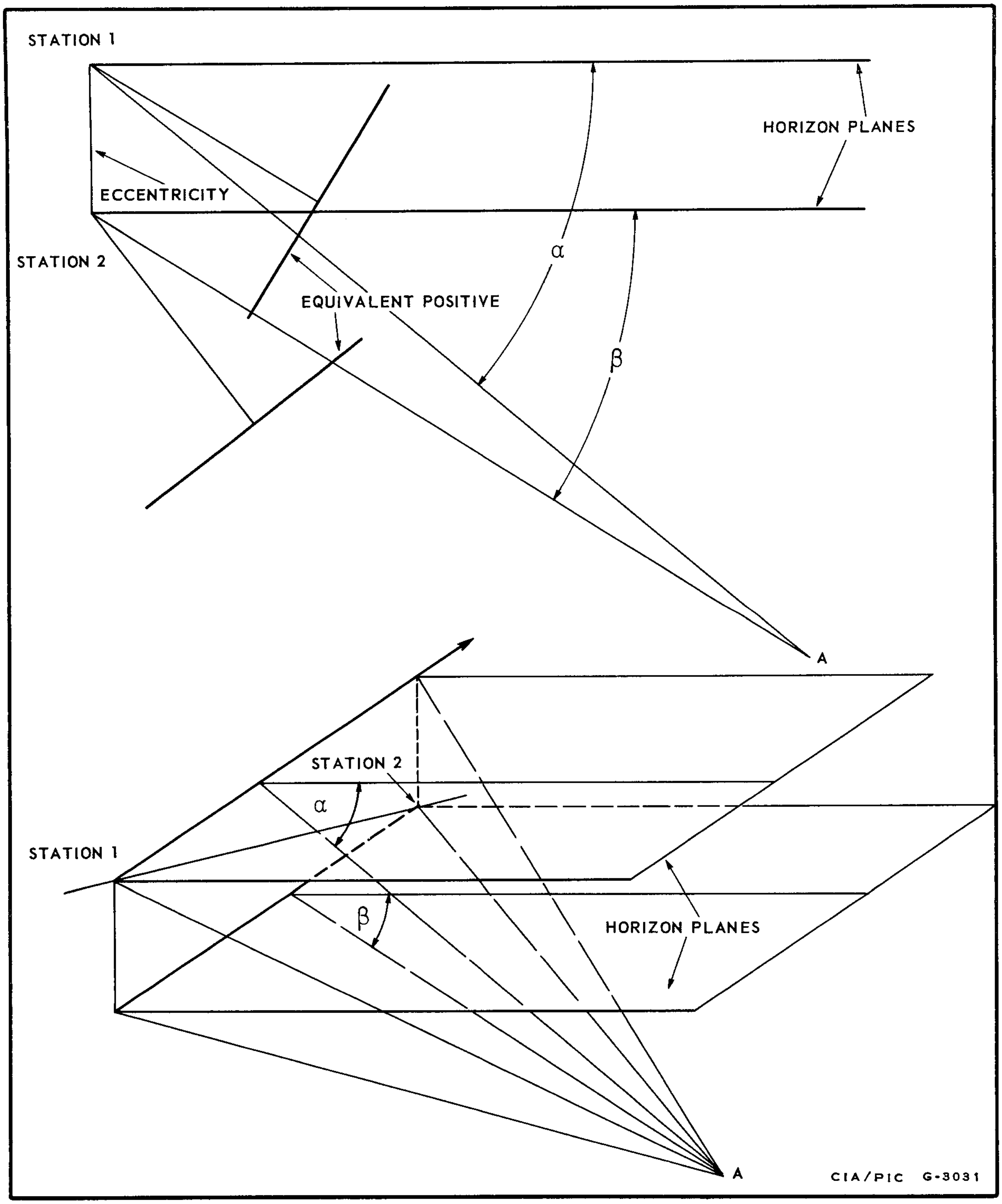

FIGURE 2. ERROR CAUSED BY STATION ECCENTRICITY, $\alpha \neq \beta$. Eccentricity illustrated as loss in altitude between two exposures

procedure is to determine the tilts of the two far obliques and transfer the tilt, exposure by exposure, down to the vertical. In Figure 3, the direction of the arrows indicates the sense of tilt transfers.

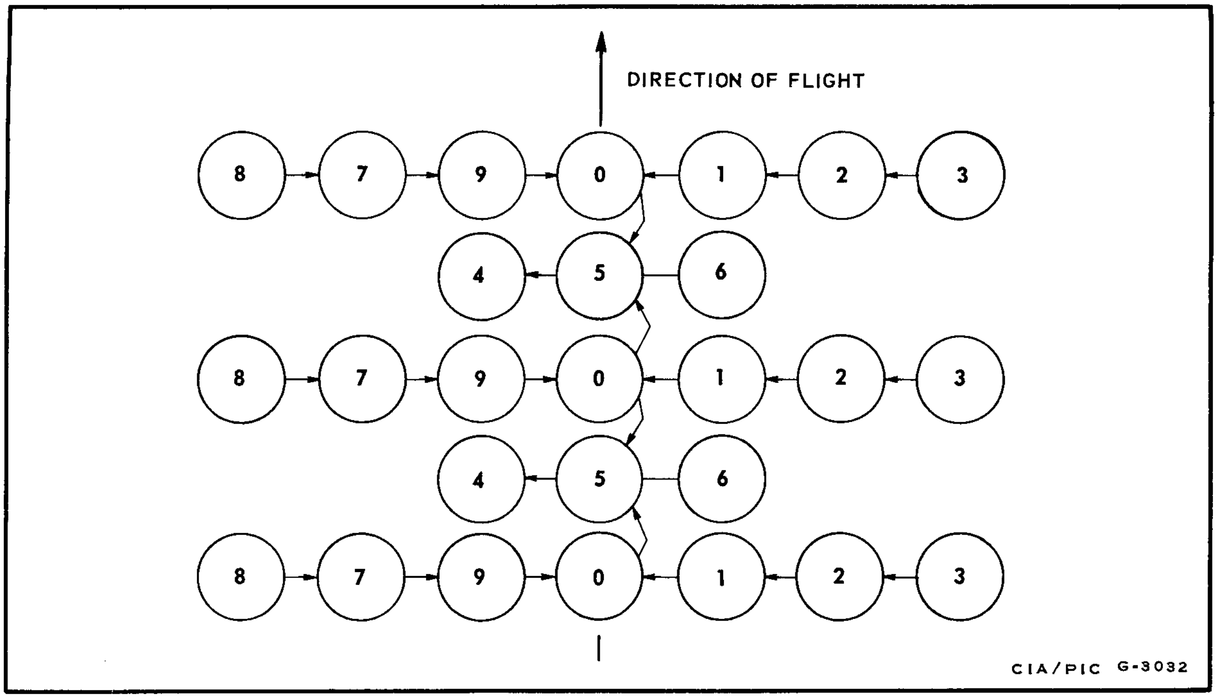

FIGURE 3. FIRING SEQUENCE, MODE ONE

Figure 4 illustrates the procedure normally used in analyzing angles. Measurements are made from the principal point along the principal plane to the apparent horizon, and the angle θ' is determined.

$$\tan \theta' n = \frac{y\theta}{f} \cdots\cdots (1)$$

Measurements are then made from the principal point to any conjugate, clearly defined image. The measurements are made parallel to the principal plane. All the angles designated as α's are then similarly determined.

$$\tan \alpha n = \frac{yn}{f} \cdots\cdots (2)$$

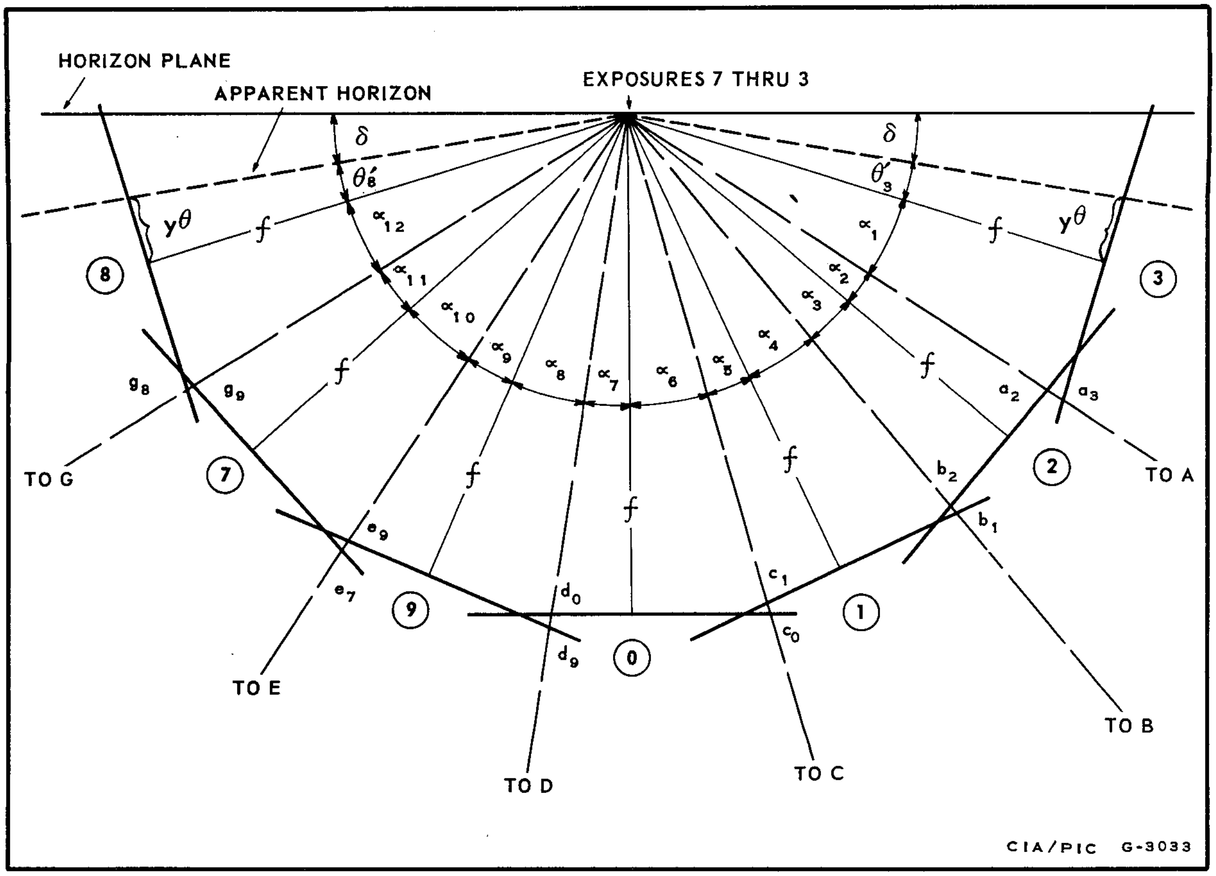

FIGURE 4. ANGLE ANALYSIS

The dip angle δ is then determined where

$$\delta = \frac{180° - (\theta'_3 + \alpha_1 + \alpha_2 + \ldots + \alpha_{12} + \theta'_8)}{2} \quad \ldots\ldots\ldots\ldots (3)$$

The tilt of any exposure is deduced as follows:

$$t_3 = 90° - (\delta + \theta'_3)$$
$$t_2 = t_3 - (\alpha_1 + \alpha_2)$$
$$t_1 = t_2 - (\alpha_3 + \alpha_4)$$
$$t_0 = t_1 - (\alpha_5 + \alpha_6)$$
$$t_0 = t_9 - (\alpha_8 + \alpha_7)$$
$$t_9 = t_7 - (\alpha_{10} + \alpha_9)$$
$$t_7 = t_8 - (\alpha_{12} + \alpha_{11})$$
$$t_8 = 90° - (\delta + \theta'_8)$$

Exhaustive tests of the method have not been conducted because of unavoidable interruptions. Least-square space resections over the Arizona control range on four exposures were computed with the following results. Results are compared with results of the proposed method.

	OBLIQUES		VERTICALS	
Exposure No	0069	0071	0070	0080
Least-square tilt	23°35'	24°28'	1°08'	0°25'
Proposed method	23°40'	24°43'	0°20'	0°22'
Difference	0°05'	0°15'	0°48'	0°03'
Swing departure from nominal on obliques	1°09'	0°44'		

On operational exposures, after transformation computations, known geometric configurations in object space were accurately represented, i.e., right angles plotted as right angles and parallel lines parallel, indicating that although no control was available the tilts determined by this method were of sufficient accuracy for practical purposes.

The determination of correct dip angle has presented difficulties. What is imperative is that the correct apparent horizons be selected on opposite obliques, i.e., exposures 8 and 3. If this is achieved, then the solution as given in equation (3) is valid. If the apparent horizons cannot be recovered, then the only recourse left is to attempt to select layers of clouds or haze that are believed to be of equal altitude above the earth's surface. If this is accomplished, then again equation (3) is valid.

The apparent horizons in the Arizona control range sampling as indicated above were easy to detect, but in operational photography a variety of haze layers and cloud formations were encountered. Experience and logical deduction have resulted in what are apparently valid tilts. The proper photographic contrast in the atmosphere layers on the high obliques is also an invaluable aid; high contrast can be controlled in the photographic laboratory if the original negatives are employed.

The procedure used on turns where there is only one imaged apparent horizon is to commence tilt determinations several fans before and after the turn, and evaluate and deduce a dip angle that is applied to the fans in the turn (see Figure 5).

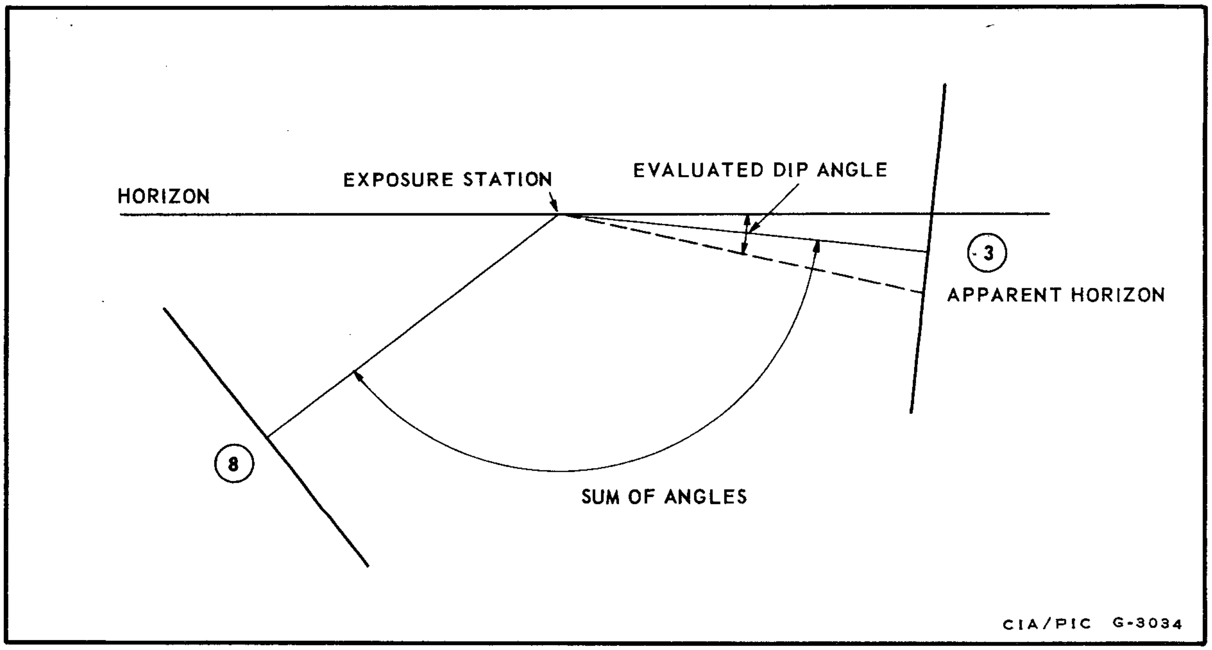

FIGURE 5. CASE OF ONLY ONE IMAGED APPARENT HORIZON

The Arizona photography used in this report was from a straight, undeviated flight. Photography taken while the aircraft is in an operational turn over the Arizona control range has been requested. It is planned to use this photography for further evaluation.

No error analysis has been attempted. Sources of error are as follows:

a. Horizon selection
b. Eccentricity of exposure station
c. Atmospheric refraction
d. Mock-up of photography on template
e. Stability of film
f. Measurement and point identification
g. Interior orientation

It is reasoned that apparent horizon selection can contribute to the greatest error. Eccentricity of the exposure station while aircraft is in a turn needs further investigation. Atmospheric refraction is assumed the same for opposite obliques and therefore cancels out. The remaining sources of error can be controlled or minimized.

The problem of transferring tilts to the fans containing three exposures from the seven exposure fans has been partially solved by graphic methods. Relative orientation procedures will be utilized when additional materials are available and when computer programs and procedures are completed. It is anticipated that it will then be possible to minimize the error in swing and to minimize errors in data transfer from one exposure to the next. It is further anticipated that operational flights will be of definite value for control extension since tilts and swings will not be accumulative.

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